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Paths of renewable energy development in small island developing states of the South Pacific

Evanthie Michalena[a,*], Jeremy M. Hills[a,b]

[a] Sustainability Research Centre, University of the Sunshine Coast, Maroochydore DC, QLD 4558 Australia
[b] Institute of Marine Resources, Faculty of Science, Technology & Environment, Private Bag, Laucala Campus, Suva, Fiji

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ABSTRACT

Pacific Small Island Developing States (PSIDS) are small and remote island economies highly reliant on fossil fuels. Although they are mainly self-governing nations, they are highly vulnerable to exogenous events such as global fuel price volatility and tropical cyclones. The work presented here targets 12 PSIDS located in the South Pacific. The analysis takes a functional approach to assess the state of the energy governance system and to determine its relationship to renewable energy (RE) penetration. Using a suite of governance, market and financial progress indicators, a range of RE preparedness levels was identified in PSIDS. Analysis demonstrated that strengthening of RE enabling indicators led to only a limited increase of RE penetration; consequently, the region has fallen behind global rates of RE uptake. Inward investment by development partners for RE demonstration projects failed to be upscaled by government-facilitated private sector. The focus on mitigating global climate change has failed to put RE into a local context; this contrasts to the strong "sense of place" and spiritual-nature of traditional Pacific communities. Thus, in energy terms, PSIDS are yet to attain a self-defined energy identity.

1. Introduction

1.1. The islands of the South Pacific

The Pacific Small Island Developing States (PSIDS) are a collection of small islands located in the South Pacific and scattered over an area equivalent to 15% of the globe's surface [1]. The work presented here concerns 12 PSIDS: Cook Islands, Republic of Fiji, Republic of Kiribati, Republic of the Marshall Islands, Republic of Nauru, Niue, Independent State of Samoa, Solomon Islands, Tokelau, Kingdom of Tonga, Tuvalu and Republic of Vanuatu. These PSIDS vary in population size, from Niue (1190 in 2014) to Fiji (886,450 in 2014) and are geographically remote and dispersed. Kiribati, for instance, has 112,000 inhabitants on 33 coral atolls spread over 3.5 million km^2 of ocean; an area larger than India.

The majority of PSIDs are independent developing nations with political systems which have jurisdictional autonomy and are part of international decision-making entities such as the United Nations. The way that the islands use this jurisdiction has very real consequences for the islands own identity and empowerment [2] and to the trajectory of development which they pursue. The economic situation in PSIDS is challenging, limited natural resources, narrowly-based economies, large distances to major markets, and high vulnerability to exogenous shocks. This is represented in various economic indicators, for example, in 2012-13, the Solomon Islands had a GNI < $1200, Kiribati had a −57% trade balance and Fiji had > 30% of the population living below the poverty line [3]. Even areas for potential economic growth such as tourism development [4] are impacted by climate change, pressures on natural, cultural and heritage resources as well as economic and social inequality [5]. However, there are significant inflows of development assistance into PSIDS which support the economy, for example, $431 per capita in the Solomon Islands (over 60% of its Gross National Income [1]) and $749 per capita in Kiribati in 2014 [6]. As Stuart, 2006 argues "outside solutions are often preferred over those that are home-grown, denying and overwhelming locally-based innovation and entrepreneurship" [7].

1.2. Challenges to a RE future in the Pacific

The Pacific islands form small energy systems with a limited capacity to host energy technologies [8]. As in similar cases [9,10], on island archipelagos, such as the Marshall Islands and Solomon islands, electric power demands need to be met by either stand-alone generation systems or through expensive grid extensions, thus many remote users

* Correspondence to: Sustainability Research Centre (ML28) University of the Sunshine Coast, Locked Bag 4, Maroochydore DC, QLD 4558, Australia.
E-mail addresses: michalena@hotmail.com (E. Michalena), jeremy.hills@usp.ac.fj (J.M. Hills).

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Nomenclature

ADB	Asian Development Bank
CROP	Council for Regional Organisations for the Pacific
EU	European Union
ESCO	Energy Service Company (or Energy Savings Company)
GCF	Green Climate Fund
GGH	Ghreenhouse Gaz Emissions
GIZ	Deutsche Gesellschaft fur Internationale Zusammenarbeit Gmbh
GNI	Gross National Income
INDCs	Intended Nationally Determined Contributions
IPP	Independent Power Producers
IRENA	International Renewable Energy Association
OECD	Organisation for Economic Co-operation and Development
PSIDS	Pacific Island Countries and Territories
PPA	Pacific Power Association
RE	Renewable Energy
SIDS	Small Island Developing States
UNEP	United Nations Environmental Program
UNFCCC; COP21	United Nations Framework Convention on Climate Change; Conference of Parties 21 (also known as "2015 Paris Climate Conference")

employ diesel generation due to its low initial cost, easy maintenance and simple operation [11]. Access to electricity through grid connection may be high in urban centres, from 61% (Vanuatu, Kiribati) to 97–99% (Cook Islands, Samoa) [1], but can be low in remote rural area such as 18% in Fiji [12]. Increasing electricity access and use also means increases in demand, for example electricity demand in Fiji has recently been increased by 5% per annum [13]. Further generating burden is created through high average distribution grid losses in Pacific islands of 14% [14], compared to grid losses in UK, the Netherlands and USA of between 4.4–7.9% [15]. Scattered data show, that, in PSIDS the main RE electricity users are government consumers, residential customers and commercial customers [16,17].

It has been argued that the right mix of RE technologies, energy efficiency improvements, and smart management can provide an affordable and reliable power supply [18]. The RE potential to work with conventional fossil fuels [8,19] or to work in hybrid power generation systems [20] so as to reduce risks in the energy mix [8] and fuel prices are some additional reasons for which RE technology in islands has received remarkable attention from both the academia and industry [21–23]. RE penetration, however, is seriously compromised by inappropriateness of technology, unavailability of skilled manpower for maintenance, unavailability of spare parts, high cost and lack of access to credit [24].

RE sources also, especially wind and solar, are inherently stochastic in nature and thus are unreliable power sources by themselves [25] especially for weak grid island systems. Estimates suggest that 26% of peak weekday demand would be the maximum RE penetration permitting grid stability in Kiribati; a similar estimate of 30% has been made for Palau [26]. Hence, especially for PSIDS the integration of intermittent RE sources in energy systems may require the development of energy storage [19]. Furthermore, negative interactions between cyclones and RE systems (such as wind generators and solar systems) further restrict the secure use of RE technologies.

Successful hydropower exploitation has been initiated before 2000 and shows significant generation in some PSIDS: 61% out of 215 MW of total electricity generation installed capacity in Fiji was from hydropower in 2013 [13], while, in Samoa there are eight small hydroelectric plants totalling 9.71 MW [27]. However, even if hydropower is proven in PSIDS, its potential is limited due to island topography island maximum elevation [28] and future projected climate change effects on precipitation [29].

Innovation is considered an effective approach for developing countries [30]. However, special features of PSIDS turn the testing of advanced technologies and creation of commercial economies of scale difficult even with development partner support [31]. Therefore, the use of more advanced technologies, in PSIDS, such as tidal and ocean energy are still are in experimental phases [32], while flexibility offered by smart grids and energy storage technologies [19,33,34] needs further consideration mainly because of the small electricity systems' size, distance between the islands, and need to transport expensive equipment from abroad [35]. This means that RE planning and modelling for islands are complex and demanding. Researchers have explored ways to technically and financially improve the RE penetration level including energy storage, hybrid systems, smart grids, and demand side management techniques [36–39].

International development partners, such as Asian Development Bank (ADB) consider that energy infrastructure and innovations are priorities for the PSIDS [40]. Increasing amounts of development assistance are also targeted at the energy sector, for example, building-up of grid-connected solar in the Pacific during the period 1997–2013 amounted at USD 31 M (55% of which coming from Japan and New Zealand) [41]. This past tendency to focus on energy generation, transmission and distribution systems, as well as tariff studies and rural electrification systems, has now shifted towards national energy policies which will increase public and private intervention on electricity power projects [40]. As a result, involvement of the private sector in islands is expanding and the role of small-medium enterprises (SMEs) towards solving energy problems is being increasingly recognised [13,42], also probably due to a growing awareness that off-grid, low-income customers represent fast-growing markets for goods and services. However, there are notable investment impediments acting against deeper access of the private sector in the electricity market such as a clear regulatory framework for private generation and supply service and the lack of a coherent, credible publicly available data on investment opportunities [40]. The corporate culture of state utilities in islands tends to be conservative, reflecting natural monopoly, technology limits, economies of scale and the drive for profitability based on lowest cost solutions [7,43].

Nowadays, however, reliance on international development assistance in the medium-term is ensured as the majority of PSIDS have announced their Nationally Determined Contribution (NDC), in Paris at the UNFCCC COP21 towards 100% electricity coming from renewable energy, but much of this commitment is conditional of external funding [44].

1.3. Research aims

PSIDS demonstrate low level of development, fragile and un-diverse weak economies and ongoing support from the international community common to much of the developing world, yet they also display miniscule scale of land resources, remoteness and extreme, and in some cases existential, vulnerability to climate change; such vulnerability is a vital area of research. Scientifically PSIDS can be seen as a suite of independent experimental units all progressing towards national and global development goals with an unique energy identify; this is fertile ground for new energy models that need to be developed in collaboration with actors and households [18] and builds on evidence that islands can have creative and sophisticated forms of governance arrangements [45,46].

On a more practical basis, energy data in the Pacific is scattered and fragmentary with little cohesive data collection. This has limited further academic analysis on energy identify and RE transition in SIDS and

academic involvement in the science-policy interface. The work presented here takes a more analytical and functional approach than previous studies to the multiplicity of the energy governance system with an aim to provide an as much as possible robust and practical guidance to further supporting RE penetration. Thus, the aims of this research are: (i) to assess the level of RE governance preparedness in the 12 PSIDS, (ii) to link the level of RE governance preparedness to actual RE penetration, and (iii) to identify key areas in which RE penetration could be strengthen throughout the Pacific region.

2. Methods

2.1. The studied Pacific islands

The research targeted twelve developing Pacific Small Independent Developing States (PSIDS): Cook Islands, Republic of Fiji, Republic of Kiribati, Republic of the Marshall Islands, Republic of Nauru, Niue, Independent State of Samoa, Solomon Islands, Tokelau, Kingdom of Tonga, Tuvalu and Republic of Vanuatu. These islands were selected because they are geographically clustered and are commonly served by the Council of Regional Organisations (CROP). All the studied islands are sovereign states as recognised by the UN except for the Cook Islands and Niue which are self-governing but with a free association with New Zealand and Tokelau which is a non-sovereign dependent territory of New Zealand.

2.2. Data collection and consolidation

2.2.1. Problems of RE implementation

The first dataset identified the problems that impede RE implementation in the 12 selected Pacific islands. To ensure consistency in approach, a common RE literature resource across all selected PSIDS was used. The RE implementation problems were identified from interrogation of the IRENA Reports "Pacific Lighthouses - Renewable energy opportunities and challenges in the Pacific Islands region" published for each of the selected PSIDS in 2013. The specific source has been chosen as IRENA has worked in all twelve islands in a uniform way and presented the findings in the same structural way which facilitated data access. IRENA is also an intergovernmental organisation working globally on renewable energy providing access to island country governments implying a degree of reliability and confidence in the information. IRENA also have ties and contacts with the majority of international development partners who are currently active in the PSIDS, therefore there is the belief that information presented has been cross-checked and verified and is as much accurate as possible.

In total, 93 problems related to RE electricity generation were identified from the IRENA reports. The problems were classified into 9 categories which seemed to be rational for RE projects that are viewed holistically as technical installations, responding to user demand and governed by specific financial, governmental, social, and environmental conditions. The 9 problem categories were Market (MA), Finances (FI), Government (GO), Social (SO), Environment (EN), Demand (DE), Fuel (FU), Grid (GR), Technical (TE). Within each problem category there were a number of identified problems (see Annex A).

2.3. Progress indicators in RE delivery

Scoping analysis of the RE implementation problems (as reports in Results section) led to a further concentration on three previously identified RE categories: FI (Financial), GO (Governance) and MA (Market). For those categories of problems/barriers, more intensive data was collected in the form of progress indicators. This method should allow a comparative assessment of the preparedness and delivery of RE. Sixty-four progress indicators were developed from IRENA "Pacific Lighthouses" reports under the FI (16 indicators), GO (30) and MA (18) categories (Table 1).

Table 1
RE progress indicators for Financial, Governance and Market dimensions.

Financial (FI)
Setting of fossil fuel price caps to prevent price manipulations
Development of RE policy together with international development partners
Efficient absorption of external funds
Existence of a net-metering policy
Financial mechanisms on place for the fees collection
Government price stabilisation policy
Grid construction / upgrade with foreign aid
Institutional billing mechanisms for the expansion of RE
Institutionalized control of electricity tariffs
Long-term governmental financial commitment for RE electrification as incentives towards private developers
RE production at a low cost (compared with the cost of solid fuels)
RE projects construction with foreign aid
RE projects studies and trials with foreign aid
Revenues collection with foreign aid
Special market conditions asking for lower energy prices
Special provisions for RE to be locally financed
Governance (GO)
Existence of a private electricity company
Existence of a public supervising electricity company
Existence of an independent energy regulator
Existing energy institutional framework
Existence of RE roadmap
Existence of institutionalized standards for oil fuel storage and transport
Existence of institutionalized energy plan during emergencies
Existing institutional framework & mechanisms for rural electrification
Institutionalization of consumers protection
Institutionally imposing policy for the use of RE
Integration of RE policy into other sectoral policies (tourism policy, etc.)
Revision and flexibility regarding RE decisions/ guidelines
Energy efficiency policy in place
Governmentally owned RE company
Governmental construction of RE (and auxiliary) infrastructure
Active NGOs in place
Collaboration between development partners and locals
Collaboration between government and NGOs
Collaboration between local energy structures (cooperatives, etc.)
Collaboration between government and energy agencies
Close institutional supervision of rural electrification policy
Collaboration between government and locals
Collaboration between government and private consultants
Collaboration between NGOs and local communities
Institutional approval of RE quality standards
Provision of maintenance support by the government
Institutional / governmental monitoring of RE implementation
Elaboration of a Non-Statutory RETs Planning (either from the government or the local communities
Participation of relevant stakeholders at the energy planning and implementation
Production of RE planning guidelines by national, regional or local governments
Market (MA)
Impact of RE implementation on other economic sectors (fishing, tourism, etc)
Measuring of RE potential
Compatibility observed between energy technologies (RE, storage systems, fossil fuels technologies, etc)
Increase of national market maturity on a specific RE technology / policy
Increase of pacific leading position on a specific RE technology / policy
Experimentation on innovative RE technologies / approaches
Tests on innovative technologies
Commercialization of innovative RE technologies
Set up of ESCO companies
Collaboration between developers and locals
Impact of RE implementation at the local market
Energy systems operated locally by local stakeholders (cooperatives, etc)
Locally setting-up of private RE enterprises
Training provision from RE local companies
Tools to local communities for RE implementation (including information)
Efficient absorption of lessons learnt
RE implementation following local know-how
Experience gained on site from RE installation and monitoring

2.4. Data collation: renewable energy installed capacity

The analysis required linking RE progress indicators to parameters associated with actual market penetration of RE in the energy mix in the form of installed capacity. RE installed capacity was used as an indicator because there was availability of data regarding RE generation across the target PSIDS islands and it is a commonly used proxy for RE penetration especially in reports of international organisations such as IRENA, REN21 etc. [47]. Three forms of information were used in assessment of actual market penetration: national installed electricity generation capacity (MW), installed capacity from RE (RE as % of total installed capacity) and proportion of RE which concerns hydropower (hydropower as % of total installed capacity). Additional data in terms of technologies in use and global installed Re estimates were taken from IRENA [47].

2.5. Data analysis

These data were analysed using standard techniques using Minitab v17. Analyses involved an ordination technique (Principal Components Analysis, PCA) and correlation analysis. Where *a priori* determined multiple tests were carried out, a conservative approach to statistical significance was used through lowering the significance threshold using a Bonferroni adaptation.

3. Results

3.1. Stage 1 – Classification of problems that hamper RE implementation

The aim of the stage 1 was to identify, codify and classify the main problems which hamper RE implementation. This would allow a subsequent analysis to focus on the key drivers in RE implementation during the stage 2 analysis. The multi-country data collected from the 12 PSIDS covered 93 identified problems in 9 problem categories; each issue being scored in binary form as “present” or “absent”. As these were collected in a region with limited systematic monitoring and reporting there was a strong but unknown possibility that these data contained some “false negatives” (i.e. there may be problems additional to those identified during the documentation review due to the imperfect coverage of the documentation). Thus, this stage was used solely for scoping the main dimensions in which a further more detailed analysis was to be targeted.

The data was consolidated under each problem category TE (Technical), SO (Social), GR (Grid), GO (Governance), FU (Fuel), FI (Financial), EN (Environment), DE (Demand) and MA (Market) for each PSIDS. This was achieved by simple linear addition of the number of problems in each category in each PIC and then standardising. A simple linear addition of problems was used as there was no scientific basis for a weighting system; it is thus assumed to provide an indicative representation of the number of problems in a problem category in the target PIC. Standardising meant that the maximum score for a PSIDS which had all problems present in the particular problem category was 100 and the minimum with no problems was 0; with 9 problem categories the maximum score for a PSIDS would be 900. The standardised problem totals and the contribution of each of the 9 dimensions was visualised (Fig. 1).

To identify the main axes of variation in the problem data for the PSIDS, a standard multivariate mathematical tool was used which identifies the main axes of variation in multivariate data: Principal Component Analysis (PCA). The analysed PCA data was the 12 PSIDS as samples described by the standardised totals in the 9 problem categories. The PCA was successful in explaining the variation in these data with a total of 58% of the variation explained by the first two axes (PCA1 = 33%; PCA2 = 25%). To determine which problem categories were aligned to the PCA axes, a Pearson's correlation was carried out between PCA1 and PCA2 scores and the problem category data of the

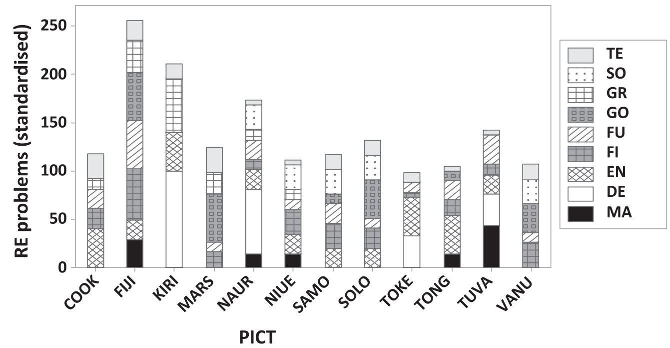

Fig. 1. The total score of standardised problems and the contribution from each of the 9 problem category dimensions, for the 12 target Pacific Island Countries. Total country problem scores are provided at the top of each stacked bar. Legend codes for problem categories are TE (Technical), SO (Social), GR (Grid), GO (Governance), FU (Fuel), FI (Financial), EN (Environment), DE (Demand) and MA (Market).

12 PSIDS. To be conservative in assessing significance with multiple comparisons a Bonferroni adaptation was used on the significance level dropping it to a significance threshold of $P < 0.0055$; this was calculated by dividing the usual significance level of 0.05 by the number of comparisons which in this case was the 9 problem categories. The two factors which were related to PCA1 were Financial ($P < 0.001$, $r = +0.88$) and Governance ($P < 0.001$, $r = +0.84$). The one factor which was related to PCA2 was Market ($P < 0.001$, $r = -0.89$); this was a negative correlation such that Market-related problems tend to decrease as PCA2 scores increase. The outcomes of the PCA were illustrated in the first two PCA axes (Fig. 2).

The PCA analysis does suggest that Kiribati and Tokelau have a relatively low weighting of the main RE issues, whereas Fiji has a heavy weighting of RE problems. However, with the possibility of “false negatives” in these data and the possibility that Fiji has a heavier burden of problems because of its more comprehensive documentation, then analysis of the relative positioning of PSIDS is taken no further. The explicit role of this scoping PCA analysis in the work presented here is to identify the main axes of variation in RE issues at the 12 country-scale which are to be followed up in more detailed work. The scoping analysis thus concludes that the three problem areas which are the main structuring parameters in determining the axes of variation in the RE problem data are Financial, Governance and Market. These three dimensions are followed up in detail in the next section of the analysis.

3.2. Stage 2– assessment of RE progress indicators

Based on the conclusion of the scoping stage, substantial progress indicator data in the Financial (FI), Market (MA) and Governance (GO) dimensions was used in the next stage of the analysis (see Methods

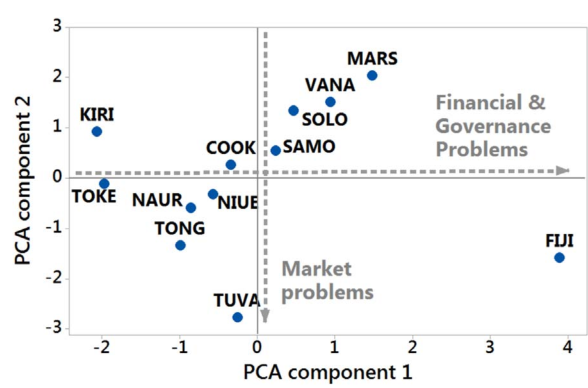

Fig. 2. Principal Components Analysis (PCA) of 12 Pacific Island Countries described by 9 RE problem categories with arrows illustrating the significant axes of variation (PCA component 1 and 2 explain 58% of the variation).

section). The aim of the stage 2 analysis was to assess progress in RE and to try to identify progress in RE governance development in the 12 target PSIDS. Progress indicators in each of the three dimensions (FI, MA and GO) were added together in a simple linear way and standardised between 0 and 100; based on similar assumptions of the approach used in stage 1. The degree of progress in the F, M and G dimensions varied between the PSIDS (Fig. 3).

The plot (Fig. 3) demonstrates a range of progress in the FI, MA and GO progress indicators across the PSIDS. All PSIDS have some degree of progression in all the three dimensions, suggesting that initiatives have been carried out regarding RE development. Progression appears to be low in certain PSIDS, such as Cook, Tuvalu and Nauru suggesting that minimal steps have been taken to date. However, other countries have developed relatively strongly in Market and Governance dimensions, such as Fiji and Tonga. Progression in developing government-based financial tools to support RE (Finance) has been relatively limited in most PSIDS, except for the Solomon Islands and Kiribati.

Combining the FI, MA and GO progress indicators to provide a single total of RE FIMAGO progress, by addition of the three dimensions, permits the overall RE progress to be assessed in the PSIDS (Fig. 4). This combined data illustrates the range of RE development in the FIMAGO dimensions and the top positioning of Solomon Islands and then Kiribati, who have been developed in a more balanced way across the three FIMAGO dimensions. These two PSIDS are then followed by Tonga, Fiji and Vanuatu which seem to have comparatively good progression in Market and Governance dimensions, but relatively weak progress in development of financial mechanisms (Finance dimension).

3.3. Stage 3 – Linking RE FIMAGO progress to RE electricity installed capacity

The assessment of progress in RE, as described by the FIMAGO indicators in stage 3 of the analysis, has shown a range of development across the targeted PSIDS. However, in climate change response terms, the important aspect to consider is *to what extent FIMAGO progress in RE has led to increased RE installed capacity*; a key dimension for a trajectory of low carbon development. In other words, have Financial, Governance and Market interventions in the RE market been associated with an increased RE installed capacity?

The relationship between RE installed capacity and FIMAGO RE progress has been determined (Fig. 5a). *There is no significant relationship between FIMAGO and the percentage of installed RE as a proportion of the total installed electricity generation capacity (*Fig. 5*a)*. In particular, Tokelau has achieved 100% RE penetration but has only achieved a relatively low FIMAGO score: suggesting that in some cases high RE penetration can be achieved without the varied governance arrangements reflected in the FIMAGO progress indicators. Solomon Islands, on the other hand have well developed FIMAGO indicators but demonstrate minimal progress in RE.

However, with a number of logical steps to clean this data there is a demonstrated link between installed RE and FIMAGO. The above outliers of Tokelau (very small non-sovereign territory; see Discussion) and Solomon Islands (due to a period governance upheaval with ethnic violence and international peacekeeping forces in the 2000s) are removed from the data as not-representative of the Pacific island governance arrangements. In addition, if hydropower is removed from RE as this is a predominately historic energy technology which is significant in a few countries (Fiji and Samoa) but is not available to many of the atoll islands (such as Kiribati and Marshall Islands), then there is a demonstrated positive relationship between FIMAGO and percentage RE (Spearman's correlation, $r = 0.79$, $P < 0.01$) (Fig. 5b).

These results suggest that for a majority of the Pacific islands there is a demonstrated association between FIMAGO progress and penetration of RE from non-hydropower generation sources. However, these results also raise a number of key questions covered in the Discussion as to why RE penetration is so low even with well-developed governance arrangements as expressed through FIMAGO.

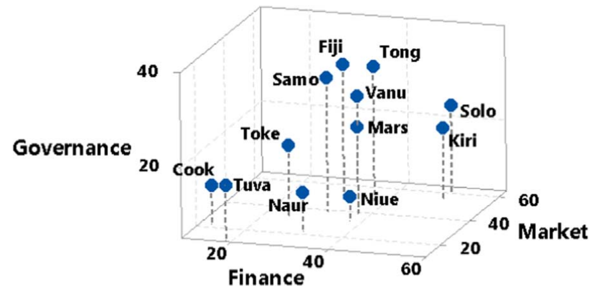

Fig. 3. Variation in financial, market and governance progress indicators in the 12 Pacific Island States.

3.4. Stage 4 – updating progress in RE implementation in the Pacific region

In 2000 in the 12 selected PSIDS, there was a significant RE base made mainly from hydropower and biomass, mainly from operations in Fiji (Fig. 6a). The study of IRENA, 2015 report states that from 2000 to 2016, 83 MW of RE were installed which represents only 57% of the existing installed capacity in 2000. Wind and solar are present but make up a very small, but slightly increasing, part of the RE mix. More recently, in terms of MW, the period from 2012 to 2015 has seem installation of < 7 MW; this is less than half the growth expected based on the average annualised growth RE over the period 2000–2016 [47].

In terms of technology, expressed as the total of RE technologies per country, there has been a spread of technology across the region (Fig. 6b). Hydropower and biomass have remained the same from 2006 to 2016, maybe reflecting the lack of land for biomass and watersheds for hydropower in many of the smaller PSIDS. The technology expansion has been in mainly in solar and more recently some introduction of wind technology. By 2015, solar has been installed in all studied PSIDS (Fig. 6b); however, the average size of installations is small as the installed MW of solar is still minimal (Fig. 6a).

Although there have been increases in installed MW and a spread of technology, in relation to global trends, RE installation in the Pacific region is lagging behind (Fig. 7). Over the period from 2006 to 2015, the selected PSIDS installed RE capacity has increased only by 60%, while the world average has increased by 90% (Fig. 7). Much of the rise in the Pacific was due to a single hydropower scheme coming online in 2011 – 2012 (Nadarivatu, Fiji: installed capacity 42 MW; see jump in curve for PSIDS from 2011 to 2012 in Fig. 7). With that plant removed the increase from 2006 to 2015 decreases from 60% to only 24% of the global increase rate.

These analyses suggest that RE generation potential has increased from 2000 to 2015 and new RE technologies have been added to islands within last years. However, the increase in installed RE is significantly lagging the global trajectory of increase and has particularly slowed down in relation to the Pacific region between 2102 and 2015. Solar technologies have been installed in all studied PSIDS but installations are small and have had little effect on the overall installed capacity of RE. Thus, in the PSIDS there has been no RE “revolution” and the sector continues to be dominated by hydropower and biomass technology which has been used since before 2000; in 2015 hydropower and biomass still represent over 89% of installed RE capacity in the studied PSIDS.

4. Discussion

4.1. Investigation of reasons for which limited RE penetration is noted despite FIMAGO progress

PSIDS have a particular and very interesting energy, political and financial identity. Fuel dependence from Third countries and financial

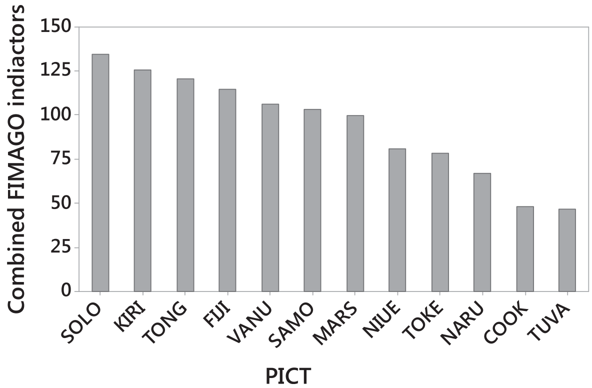

Fig. 4. The combined RE FIMAGO progress indicators for the 12 target Pacific Island Countries, ranked from most to least progressed RE development.

dependence from international development partners are contrasted to governmental freedom in decision-making. This balance of dependence and freedom help is noticed across all studied PSIDS.

Although there are exogenous and endogenous commonalities within the PSIDS, there are major differences between the countries in terms of the level of governance preparedness and actual RE implementation. In terms of installed RE as a % of total installed capacity, some PSIDS (such as Tokelau, Fiji, Kiribati and Samoa -Fig. 5a-) demonstrate significant progress. However, a good complement of this RE progress is hydropower in Fiji and Samoa (Fig. 6a). Removal of the hydropower component aligns installed RE much closer to other PSIDS without hydropower (Fig. 5b). Much of this hydropower has been generating since year 2000 (Fig. 6a) and is a tried and tested technology in the Pacific. In this Region, hydropower is usually a centralised government-led installation and therefore has more similarity to centralised grid-feeding diesel plants, and is thus developed and operated under more established financial and institutional procedures.

Other countries, mainly atoll islands are too small to have watersheds and rivers and do not have any potential for hydropower but have made significant progress on RE penetration. The most striking example is Tokelau which demonstrates 100% renewable-based electricity production even though it is the fourth-lowest in FIMAGO progression (Fig. 5a). The energy identify of Tokelau however, is rather different as it is a "non-self-governing territory" as Tokelau has New Zealand as its "motherland". This connection to a "motherland" and the eventual loss of some degree of self-jurisdiction is balanced by direct access to financial resources, which funded a shift from 100% diesel to 100% PV generation and associated storage systems in three atolls of Tokelau (project completed in 2012 [13]. The low scores of FIMAGO indicators in Tokelau (Fig. 4) would not affect the instantaneous shift from 100% fossil fuels to 100% RE as it was a project-based refit and did not require any special governance mechanisms with local stakeholders, local developers and the need of special financial instruments. This means that even though many other PSIDS are small, they are still beyond the scale of a "single project" refit and this is why there is the need to create governance mechanisms (as reflected in FIMAGO) to help advance RE penetration.

Choosing to invest on the basis of an ESG-themed (Environmental, Social and Governance) approach is leading to increase of RE Market [48–50]. However, in the case of PSDIS, although PSIDS demonstrate a range of level of preparedness for a RE transition, significant strengthening of financial and governance systems has led to minimal increase in RE installation with levels around 20% (excluding hydropower) at the highest FIMAGO status; a growth which is falling well behind the global rate since 2006 (Fig. 7) [18]. Or, in some PSIDS, even barely existent as in the Solomon's Islands which have region-leading FIMAGO status but negligible RE penetration. Further, technologies speaking, hydropower and biomass (only in Fiji) dominate the Pacific installed RE landscape and have done since 2000 (Fig. 6a). There have been quite a number of technological introductions to islands, especially in solar from 2006 to 2012 (Fig. 6b), but this has led to a minimal increase in RE installed capacity (Fig. 6a). The same conclusions on failing to promote conventional infrastructure development in PSIDS is noted from other authors as well [51]. Those findings (a lack of RE progression despite significant levels of progress in RE governance and financial dimensions as well as a regional picture of weak or failing transition to further RE beyond historically well-established centralised systems) are crucial in light of the widespread development agenda rhetoric of low carbon transition in SIDS. They also might be due to the governance context that surrounds the South Pacific RE environment:

Authors have provided critical insights into enabling institutional capacity to leapfrog in a developing country context (e.g. [51–53]. Yaquoot et al., 2016 in particular stress that effective RE penetration policies set by government should be long-term conducive policies which include a number of facets: an appropriate regulatory framework, financial incentives, technology and skill development, internalization of externalities in the cost of energy, withdrawal of fossil fuel subsidies, development of specialized institutions, and growing local community participation and awareness [24].

The PSIDS included in the here-presented analysis seem to have an active and solid institutional framework in place in terms of roadmaps and policies which address the majority of above mentioned enabling factors and which include provisions and targets for RE. For example, the Samoan energy policy targets aim to provide sustainable and reliable electricity services by improving the collection performance, to improve reliability and quality of supply by removing transmission

a) all installed RE

b) all installed RE excluding hydro with best fit straight line fitted excluding Solomon Islands and Tokelau.

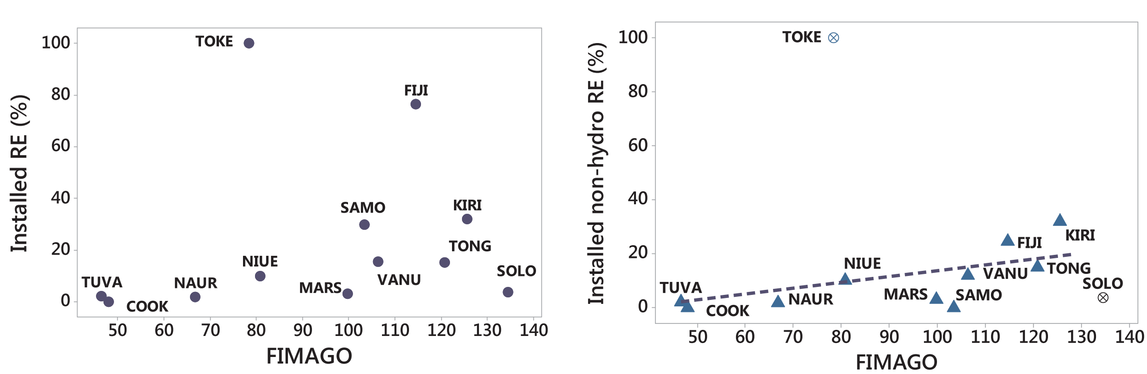

Fig. 5. The FIMAGO progress indicators of RE plotted against the percentage of installed renewable energy for the 12 targeted PSIDS:.

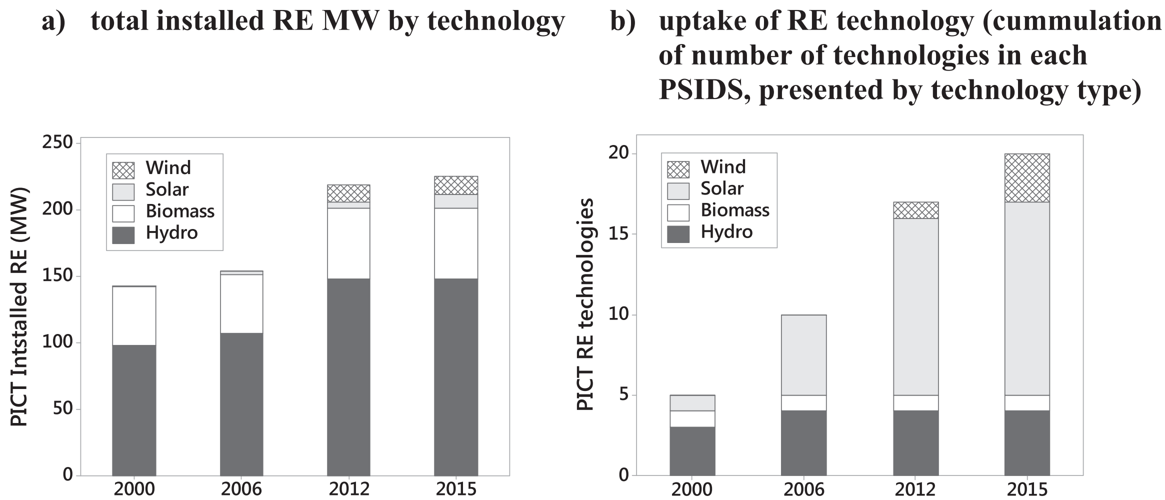

Fig. 6. Changes in RE in the 12 selected PSIDS for year 2000, 2006, 2012 and 2015: a) total installed RE MW by technology b) uptake of RE technology (cummulation of number of technologies in each PSIDS, presented by technology type).

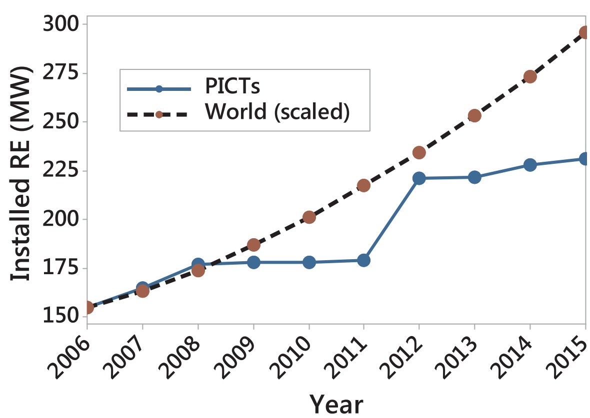

Fig. 7. Comparison of the growth in installed RE between the world and the 12 target PSIDS (world MW installed is scaled to PSIDS in 2006).

obstacles and to meet growing peak demands by increasing capacity requirements [40].

This existence of energy policies and institutional frameworks is a valuable asset for PSIDS, especially when they simultaneously have jurisdiction to promulgate energy regulations and energy planning policies without the need of consensus or approval from a "motherland" as other islands do (for example, the Canary Islands where decisions on energy are linked to the Spanish "motherland" and the Spain's legal framework [8]. This means that PSIDS, have national control on strengthening the already existent government enabling features for RE deployment systems to allow further RE penetration. Thus, the lack of additional RE penetration in the Pacific even when FIMAGO progression is evident, suggests that the reasons for low penetration *are not fully related to the government enabling environment*.

In addition to governments, development partners seem also to be founding elements on the financial RE progress in PSIDS, working with the private sector for creation of demonstrative installations and with the government directed roll-out. Through this approach, RE penetration in the Pacific region is happening, albeit slower than global averages, and new technologies are being introduced into new islands.

The 12 PSIDS presented in this work had a total of 228 MW installed RE in 2015. This represents just 0.2% of the installed RE capacity of Germany or < 0.015% globally [47]. With the inevitable minimal RE mitigation significance of PSIDS on a global scale, then investment in RE in PSIDS would seem be of a challenging rationality. PSIDS investment risks are also apparent, for example where well-developed RE governance has not led to a significant RE installation (Solomon Islands), or where extreme events reduce operational ability of RE as well as making the wider grid system inoperable (e.g. Cylcone Winston, Fiji). This situation compares unfavourably to (for example) the mature German RE governance system, where German municipalities play a crucial role in energy affairs demonstrating five distinct and important modes of governance in the field of RE policy [54]. In Germany, RE penetration looks increasingly cost-efficient and closer to grid-parity; in addition to the lack of cyclones.

The minimal contribution of RE interventions in PSIDS to global GGH emission reductions means that a more diversified and well-founded agenda for RE needs to be appreciated for PSIDS. With high levels of vulnerability in PSIDS, interventions in the RE sector could be targeted to not just secure global mitigation benefits but also accrue adaptation co-benefits by helping build resilience in communities in a localised way. However, this requires a higher-level dialogue and ambition to achieve both mitigation and adaptation in a socio-culturally sensitive manner. It also needs to be accompanied by an institutional move away from the focus on carbon accounting mechanisms for RE projects used by many development partners, funding instruments such as the GCF (Green Climate Fund) and expressed by PSIDS governments as part of their Nationally Determined Contributions (NDC) submitted to UNFCCC.

Within all this interplay between national governments and international development partners, the role of private sector worths further investigation. Some instruments have been put in place to support RE deployment. For example in Fiji the Fijian Reserve Bank introduced a loan guarantee scheme, established mandatory lending ratios and called for commercial banks to lend 2% of their combined loan portfolio to RE projects. In addition in Fiji, the Sustainable Energy Financing Project of the World Bank has developed a portfolio of 44 private sector loans totalling USD $9.7 m, [55]. In spite of these financial incentives, installed RE in Fiji has been largely static since 2008, except for one large hydropower installation (Nadarivatu, Fiji) [56].

The negligible uptake of incentivised RE installation by private sector suppliers is even more lacking than initiation of RE by private sector companies. The lack of private investment in the energy sector is attributable to many causes, but four key factors are the unfavourable climate of investment for private investors, the inadequacy of the Independent Power Producers (IPP) tariffs offered by the state utility (Fiji Electricity Authority), the lack of clear regulatory frameworks for private generation and supply service and the lack of a coherent, credible publicly available data on investment opportunities [40].

The weakness of the interface between government and the private sector, even when incentivised by external loan agents, might also be a

key reason for which the preparedness of RE, as measured here by the FIMAGO progress indicators, has failed to lead to significant growth of installed RE in the region. The here study thus further validates the opinion of Wolf et al. [13], according to which one of the most pressing regional issues is to strengthen the involvement of the private sector in RE penetration. A stronger private sector interventions can lead to the creation of economies of scale and the absorption of technical and financial risks. Within the process of private sector strengthening however, it is important to note that the private sector should organically grow rather than being driven exclusively by development partners grants or soft loans.

Sustainable energy planning cannot be implemented unless institutions restructure their protocols and behaviours in close cooperation with the development partners, developers and local communities. The institutional preparedness associated with energy planning was named "formal policy process" and the wider engagement "informal elements" [57]. In PSIDS, central government freedom and progressive structuring of the formal policy process (as reflected in the FIMAGO indicators) have progressed, yet the role of local governance has been neglected. Access of local communities to energy information is limited [58]. This contrasts to what is happening to other islands around the world where local dynamics are key-components of RE implementation [59]. Which is impressive when taking into consideration the vibrant social communities existing in PSIDS with many activities based on volunteerism and a high level of representation in the Pacific arena.

This lack of local information could be further accentuated by the perceived negative effects of development on the traditional way of living of the islands local communities as explored by Bennett and Dearden [60]. RE drivers which may support global mitigation, may not find strong resonance with traditional societal perceptions which tend to be much more locally-focussed and have acknowledged influences on decision making related to spirituality and connectedness to Nature [61]. The secular edification of RE typified in development partner and governmental initiatives may be a barrier to local engagement. Time is necessary for locally-new technology to mature in local society's mind [62,63] and with pressing climate change challenges, time is not a friend in the South Pacific Region [64]. Therefore, overcoming existing constraints to develop a progressive increase in local awareness in energy sustainability and security may help the penetration of RE match governmental rhetoric.

5. Conclusions

In the Pacific SIDS, with hydropower removed, RE penetration is positively related to increased strength in the RE progress indicators; however, the level of RE progression is minimal. Increases in RE installation in the selected PSIDS over the last 16 years represent only a 57% increase of the existing installed capacity in 2000 and from 2006 to 2015 the selected PSIDS installed RE capacity increased only about 66% of the overall global increase. While governments have created significant enabling assets and development partners have been supporting demonstrative installations, significant RE upscaling and further penetration is not apparent.

From assessment of the involved governance context it seems that although governmental and institutional structures are in place, the private sector presents a systematic weakness towards organically-driven upscaling. Willingness for inward investments by development partners for demonstration projects contrasts with limited upscaling through government-enabled private sector mobilisation approaches. Development partners and financial support act as a prerequisite for RE progress rather than an auxiliary RE leverage tool. The failure to put RE into a local context, to emphasise local resilience building and to move the rhetoric from a secular nature to one which encompasses the "sense of place" and spiritual-nature of traditional Pacific communities, all help to block further community engagement towards RE.

Literature presents examples of islands which rely heavily on financial aid and technical assistance from their motherland [65]. Pacific islands seem to have not yet progressed very far along a trajectory to the ambitious RE targets which they have set even, or achieved energy security, even with ongoing development partner support. Thus, in energy terms, PSIDS are yet to attain an energy identity which reflects their own needs and self-governing status.

Annexure A

See Table A1.

Table A1
RE implementation problems from IRENA Lighthouse reports (2013) classified into 9 problem categories.

MARKET (MA)
Limited expertise in marketing strategies
Lack of consistency between plans and realization
Operational problems of the main electricity provider
Immature business environment
Preference for solid fuels instead of RE
Non efficient absorption of lessons learnt
Limited expertise in business management in rural areas
FINANCES (FI)
High cost of electricity provided
Complexity in the structure of electricity tariffs
High governmental substitution of electricity costs
Limited provision of electrification services to rural areas due to high costs
Selling electricity power below its real cost
Over-subsidized rural electricity from urban areas
High RE fuel harvesting costs
High cost of RE fuel transport at the site of its demand
Location of biomass waste in lands with limited financial value
High operational cost of RE systems
High cost of electricity transmission, eg. construction of grids, biomass transport, etc
Low electricity payments from users
Lack of access to financial sources
Non efficient absorption of external funds
High economic dependence from development partners
Lack of funds for RE maintenance
Limited financial viability due to small populations in place
High costs of pre-payment meters
High cost and technical difficulties in the construction of RE auxiliary equipment
GOVERNMENT / INSTITUTIONAL POLICY (GO)
Lack of governmental support
Lack of centrally organized training
Under-investment, limited staff and resources of the governmental body
Inadequate governmental supervision
Inadequate staff and resources of the governmental body
Lack of confidence to the government
Intense political interference
Fragmentation of governmental supervision
Little interaction with the supervising governmental body
Lack of suitable institutional structure for RE equipment maintenance
Lack of institutional support on the cost-efficient side of electricity demand
Inadequate legislation to protect electricity consumers
Changes in the institutional framework
Inconsistency between decisions and implementation
Lack of confidence due to non repairs

(*continued on next page*)

Table A1 (*continued*)

Lack of consistency on RE implementation plans
Unexploited RE potential
SOCIAL (SO)
Vandalism
Lack of confidence to partners
Low population on site
Dispersed population over the area
ENVIRONMENT & LOCAL NATURAL FEATURES (EN)
Need for studies regarding release of discarded RE equipment
High environmental cost in transporting biomass
Local physical conditions which hamper RE implementation, e.g. limited land area, poor soil
Difficulties in land access for the RE implementation
Difficult climate conditions
DEMAND (DE)
Electricity demand exceeding RE system specific designed capacity
Irregularity of RE demand
Limited demand for RE
FUEL (FU)
Issues in the quality control of RE fuel to be used (especially when biomass is concerned)
Inadequate quantity of RE fuel locally
Decline of the local source used to be use for RE electricity production
Limited continuity of RE fuel supply
Alternative uses of RE fuels, rather than producing energy
Limited data for RE potential
Low operational fuel efficiency
Lack of RE fuel supplier
Irregular fuel supply
Poor fuel handling / management

Table A1 (*continued*)

GRID (GR)
Difficulties with grid interconnections
Electricity system overloaded because of bad use of RE system
Technical concerns regarding grid stability from RE implementation
Need for appropriate grid modelling and additional grid equipment, such as storage facilities
Exogenous parameters such as, for example, the high cost of imported coconut oil
Problematic RE storage in place
Unsuccessful collaboration of RE systems with the grid due to technical mistakes
Little interaction with the grid due to use of inappropriate RE equipment
TECHNICAL (TE)
Poor electricity facilities in place
Limited local technical capacity
Insufficient local training
Inadequate maintenance of RE and components (such as batteries)
Technical difficulties in the construction of RE auxiliary equipment
Technical difficulties present in making RE equipment viable
Need for development of additional infrastructure, such as storage systems
Lack of RE spare parts
Limited data obtained [when it concerns sales of electricity]
No reliable data on sectoral energy demand
Operational stop of RE plant / technology implemented
Inappropriate use of RE components (batteries)
RE batteries affected from high temperatures
Lack of RE standardised design approach
Complexity of RE systems design
Loss of foreign technical support
Not RE progress beyond the experimental phase
Lack of safe transport infrastructure
Environmental issues, such as noise and safety in densely populated sites

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